

“APISAT2014”, 2014 Asia-Pacific International Symposium on Aerospace Technology,
APISAT2014

Numerical Study on Drag Reduction by Micro-Blowing/Suction Compounding Flow Control on Supercritical Airfoil

Cai Junxuan, Gao ZhenXun*

Beihang University, No.37 Xueyuan Rd. Beijing 100191 China

Abstract

Micro-Suction technique(MST) is proposed by the development of micro-blowing technique(MBT). Current experiments and numerical studies are mostly focusing on MBT, micro-suction flow control in turbulent boundary layer remains unstudied. Thus, based on 2D-RAE2822 supercritical airfoil, numerical research on MST and MB/ST compounding flow control have been carried out. And Micro-Porous Wall Model(MPWM) is used to represent the real effects that the blowing and suction of the micro-porous wall has on the surface flow. The numerical results of micro-suction indicate that micro-suction control is capable of inducing a lower pressure zone in front of the micro-porous zone, and a higher pressure zone in the rear end. Given that micro-porous zone is placed on the particular section of airfoil, where the pressure drag direction is backward parallel to free-stream direction, the reduction of the pressure induced by micro-suction control can result in the decrease of pressure drag. Finally, combining the previous study on the MBT, a compounding configuration of micro-blowing/suction flow control on RAE2822 airfoil is proposed. The compounding configuration can take the advantage of both micro-blowing and micro-suction, over 20% increase of the lift and up to 15% decrease of the drag can be realized. Therefore, the compounding flowing control of micro-blowing/suction shows a great potential for the flow control on aircraft.

© 2015 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of Chinese Society of Aeronautics and Astronautics (CSAA)

Keywords: MBST; flow control; drag control

* Corresponding author. Tel.: +86-10-8231-5396; fax: +86-10-8231-5396.

E-mail address: gaozhenxun@hhu.edu.cn

1. Introduction

Micro-Suction technique (MST) is proposed by the development of micro-blowing technique (MBT). Different from the traditional suction control, The diameters of the micro-porous channels are in the range of 0.1~0.3mm, which are much smaller compared with the thickness of boundary layer, and the amount of air needed for micro-blowing is merely the order of 10^{-3} ~ 10^{-2} to the average mass flow rate of the boundary layer. Current experiments and numerical studies are mostly focusing on MBT, till now MBT has been largely developed via many experimental researches and several numerical researchers. Hwang of NASA John H. Glenn Research Center, through massive flat plate experiments, found that MBT can attain a range of 50%~75% skin friction drag reduction in both subsonic and supersonic conditions. In the meantime, micro-suction flow control in turbulent boundary layer remains open. Thus, based on 2D-RAE2822 supercritical airfoil, numerical research on micro-suction and micro-blowing/suction compounding flow control has been carried out. And Micro-Porous Wall Model(MPWM)^[2] is used to represent the real effects that the blowing and suction of the micro-porous wall have on the surface flow. In the present paper, different locations of micro-porous zone on airfoil surface have first been studied. Then according to the previous work on mechanism of drag reduction by MBT on supercritical airfoil, the micro-blowing/suction compounding flow control has been further studied.

The MPWM formulates the macro-scaled collective characteristics of a porous wall composed of micro-channels, utilizing the asymptotic analysis, in conjunction with the Darcy's law in theory of porous media flows, to represent the real effects that the blowing and suction of the micro porous wall has on the surface flow^[3]. The detailed concept results from Ref[3], here only the idea and the conclusion formulas are presented.

When defining computing settings, the micro-porous zone is simplified into a type of boundary condition to simulate the micro-blowing effects. The inlet/outlet speed q at an arbitrary point (x_1, x_2) on the micro-porous wall can be written as

$$q(x_1, x_2) = \varphi \frac{F \rho_{\infty} U_{\infty}}{\rho_{ex}} \quad (1)$$

In which $\varphi(x_1, x_2) = n\pi d^2$ represents porosity, and d represents the diameter of hole, also all the holes are assumed to have the same diameter. $n(x_1, x_2)$ represents the density of the hole number per unit wall area, ρ_{∞} represents the density of the coming flow, U_{∞} represents the coming flow velocity, and ρ_{ex} represents the gas density at wall surface. F is defined to be the blowing fraction as

$$F = \frac{\rho_{ex} U_j}{\rho_{\infty} U_{\infty}} \quad (2)$$

Where U_j is the average blowing speed at the entering cross section of the micro-pore/channel, and $U_j \neq q$. In practical computing application, the blowing fraction F and porosity φ are given as parameters, and ρ_{ex} is calculated as gas density at wall surface by CFD. Hence, the outlet speed q at any point of the micro-porous wall can be figured out directly by Equ (1).

2. Computational Method

According to previous work on the configuration of MBT on airfoil, the location of micro-porous zone has a significant influence on drag control. Thus 5 different locations on upper wall surface are separated to study respectively. The sketch of airfoil and geometry parameters of the locations are shown in Fig.1.

Numerical simulation is run by the finite-difference-based CFD program (ACANS) developed by National Laboratory for Computational Fluid Dynamics, and the program has been validated by several related computing cases [4]. The calculated area is partitioned with C-H type grids, as shown in Fig.2. The first layer of grid in the boundary layer is about 0.01mm away from the airfoil wall.

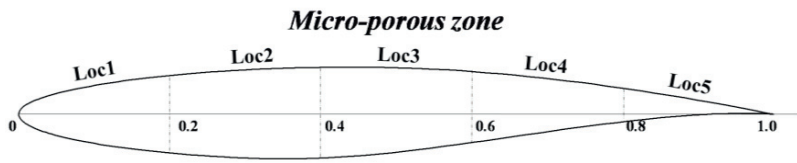


Fig.1. Locations of the micro-porous zones

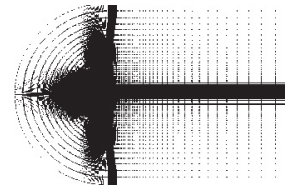


Fig.2 Grid of calculated areas

In the computation, the NASA-PN23 micro-porous zone^[5] is selected and the porosity $\phi=25\%$. In the research of Li[6], the drag reduction of micro-blowing increases linearly with the porosity ϕ , while in practical application the structural stiffness and strength are taken into account, and therefore $\phi=25\%$ is chosen to be a proper value. The parameters of air at the altitude of 10.7Km are chosen to be the coming flow parameters. The coming flow Mach number is $Ma_\infty=0.734$, Re number is 6.5×10^6 .

3. Numerical Results and Analysis

3.1. MST numerical results and analysis

Fig.3(a) gives the lift and drag ratio, which is defined as the ratio of lift and drag with micro-suction to that of the solid wall, and the angle of attack here is 0° . With MST flow control on 5 different locations on upper wall surface, MST can both change the lift and drag values. For the lift, MST on any location will increase the lift, and more additional lift will be achieved when micro-porous zone is placed near the rear end. While for the drag, micro-porous zone on middle section of the airfoil, especially Loc3 can slightly reduce the total drag by about 1%, whereas the front and trailing edge will increase about 1~2%.

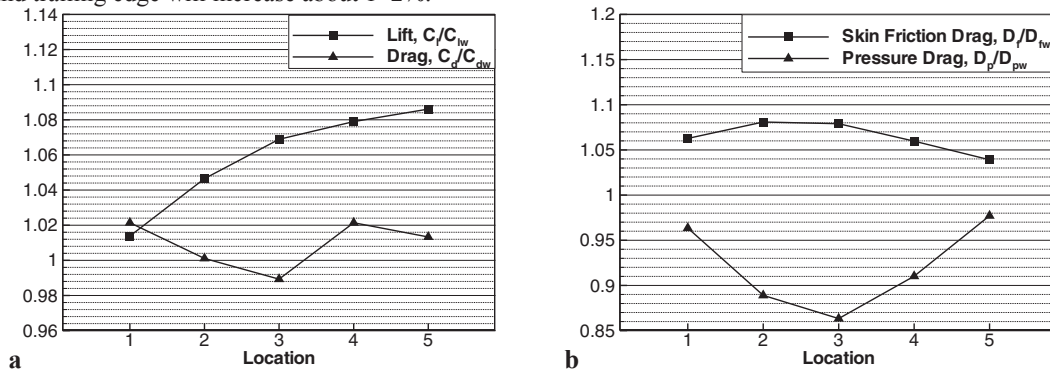


Fig.3. (a)The sketch of lift and drag; (b)The sketch of pressure drag and skin friction drag

Furthermore, the reasons behind the change of lift and drag are here to be discussed. Fig.3 shows the ratio of pressure drag and skin friction drag. The delta symbols in Fig.3(b) represent the ratio of pressure drag with micro-suction on different locations to that of the solid wall, D_p/D_{pw} . And the square symbols in fig.3(b) represent the ratio of skin friction drag with micro-suction to that of the solid wall, D_f/D_{fw} . It finds that MST increases the skin friction drag no matter where the micro-porous zone is placed, and the increments are between 5% to 9%. Meanwhile, different to skin friction drag, MST always decrease the pressure drag in all locations. And with MST control on the middle section of the airfoil surface, up to 14% of the pressure drag can be reduced, which causes the total drag reduction. And when micro-suction is placed on the front and trailing edge of the airfoil surface, MST control is able to reduce the pressure drag as well, but apparently weaker than Loc3, as shown in fig.3(b).

Fig.4(a) gives the ratio of surface pressure with MST control to that of the solid wall. It is very clear that micro-suction zone has an apparent change on the surface pressure, inducing a low pressure zone in front of the micro-porous skin, named MST pressure trough for short. In the meantime, at the rear end of the micro-porous skin, a high pressure zone can also be induced, named MST pressure peak for short. These peak and trough always appear wherever the micro-porous zone is placed. Furthermore, with these pressure peak and trough phenomenon, micro-suction on Loc5 can induce the biggest area of low pressure zone, because the whole pressure on upper surface is in the pressure trough, which is of benefit to the increase of lift. Besides, if upper surface is separated by two part, the front-half section and the trailing-half section, the former section's portion possesses backward pressure force, and the later section's portion possesses forward pressure force, then combining the micro-suction peak and trough phenomenon, MST control on Loc3 (middle section of the airfoil) is capable of both decrease the pressure on the front-half section by the induced MST pressure trough and increase the pressure on the trailing-half section by the induced pressure peak. This kind of flow control is an ideal way to reduce the pressure drag, and this configuration is demonstrated to reduce the pressure drag by up to 14% as shown fig.3(b).

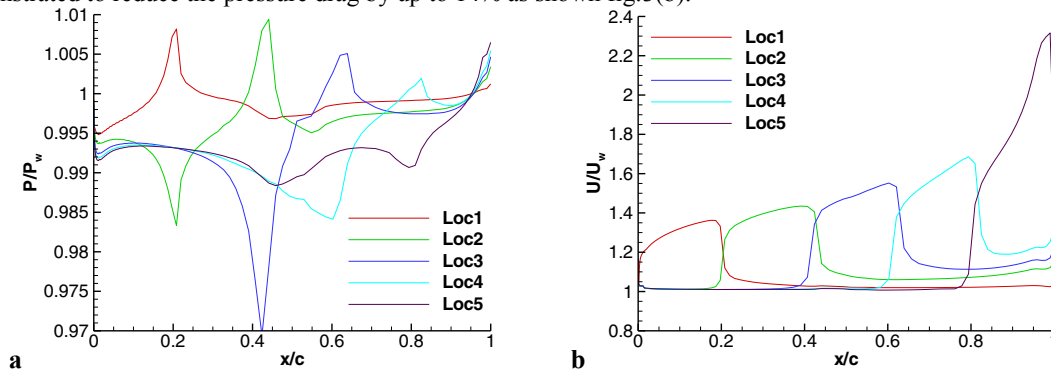


Fig.4. (a)Sketch of surface pressure; (b) Sketch of tangential velocity

The skin friction drag of airfoil is mainly determined by the gradient of normal velocity in near wall region. Fig.4(b) shows the tangential velocity in the first layer grids around airfoil for different configurations. It finds that, when micro-blowing is acting on each location, a significant increment of tangential velocity happens thereby. Then larger tangential velocity causes greater gradient of normal velocity, which results in greater shear stress. Although micro-suction on Loc5 attains the biggest area of the increment of tangential velocity in fig. 6, the absolute flow velocity is much lower than the front section of the airfoil, as a result, micro-suction on the front and middle section of airfoil achieve more increment of skin friction drag, as shown in fig.3(b). Thus, for skin friction drag, MST control may not be an efficient method, and the main positive effect of MST control performs in the re-distribution of surface pressure, which contributes to the pressure drag and lift control.

3.2. MB/ST compounding flow control results and analysis

According to the previous work on flow control by MBT, it finds that micro-blowing will induce a high pressure zone in front of the micro-porous zone and a low pressure zone in the rear end, forming the MBT pressure peak and the MBT pressure trough, which are just opposite to the MST control. When applying MBT in the airfoil, it suggests that micro-blowing-porous zone should be placed after the thrust zone on lower wall, whose portion possesses forward pressure force and upward lift force, then most of the high pressure induced by micro-blowing will be constrained in the thrust zone and an additional thrust will be achieved. This can significantly reduce the pressure drag and increase the lift either.

Table 1 gives the results of simulation, and Fig.5 gives the comparison between three different MB/ST flow control, it can be found that MB/ST compounding flow control is apparently better than MBT or MST single flow control, approximately equals the total effect of MST and MBT. The MB/ST compounding configuration keeps the advantages of both MBT and MST flow control, and further increases the lift and decrease the drag of airfoil. It can

attain 19%~26% increment of lift, and reduce about 15% drag.

Table 1. gives the numerical results of the MB/ST compounding flow control ($Ma_\infty=0.734$, $\alpha=0^\circ$, $F=0.008$ & 0.5)

Micro-porous zone				C_l/C_{lw}	D_f/D_{fw}
Upper surface		Lower surface			
Location	Blowing Fraction F	Location	Blowing Fraction F	1.0000	1.0000
Loc1	0.008	Loc5	0.05	1.1900	0.8921
Loc2	0.008	Loc5	0.05	1.2225	0.8630
Loc3	0.008	Loc5	0.05	1.2359	0.8486
Loc4	0.008	Loc5	0.05	1.2293	0.8662
Loc5	0.008	Loc5	0.05	1.2603	0.8758

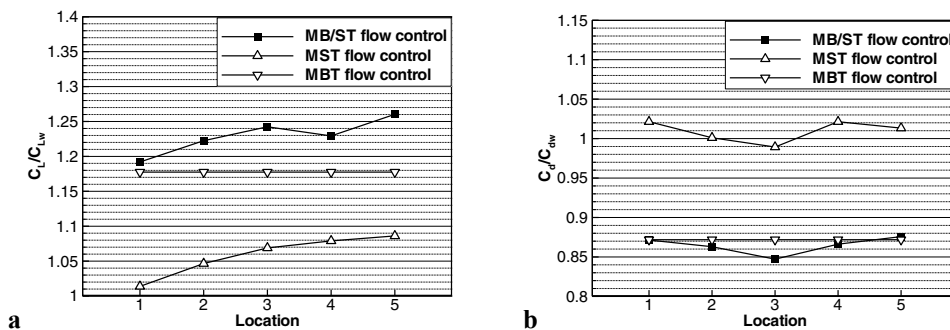


Fig.5. (a)The sketch of lift; (b)The sketch of total drag

4. Conclusion

MST and MB/ST flow control on 2-D airfoil have been studied in the presented paper. The results indicate that both MBT and MST flow control can change the skin friction drag and alter the distribution of airfoil surface pressure:

- For the skin friction drag, MBT reduces it slightly whereas MST increases greatly;
- For the pressure drag, both MBT and MST reduce it greatly;
- For the lift, both MBT and MST increase it greatly.
- Based on the above conclusions, The compounding configuration is studied, and it believes that the characteristics of both MBT and MBT can be kept down in the MB/ST compounding configuration, the total drag remains the same as MBT control, because MST control do not significantly change the total drag. But the lift is greatly increased, which is contributed by both MBT and MST.

References

- [1] Hwang D P. Review of Research into the Concept of the Micro-blowing Technique for Turbulent Skin Friction Reduction[J]. Progress in Aerospace Sciences, 2004, 40: 559-575.
- [2] Li J, Shen J, Lee C H. A Micro-Porous Wall Model for Micro-Blowing/Suction[J]. Scientia Sinica Series G, 2014, 44(2): 221-232.
- [3] Li J. Modeling for Flow Control Technique via Micro- Blowing/Suction and Numerical Study on Drag Control[D]. Beihang University, 2009.
- [4] Gao Z X, Jiang C W, Lee C H. Improvement and application of wall function boundary condition for high-speed compressible flows[J]. Sci. China Tech. Sci., 2013, V56(10): 2501-2515.
- [5] Hwang D. P. Skin-friction reduction by a micro-blowing technique. AIAA J, 1998, 36(3): 480-481.
- [6] Li J, Lee C H, Jia L P, et al. Numerical Simulation on Influencing Parameter of Micro-Blowing Technique[J]. Journal of Beijing University of Aeronautics and Astronautics, 2010, 36(2): 218-222.